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Method and apparatus for producing a high resolution image

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The present invention relates to a method and an apparatus for producing a high-resolution image.

Solid state imaging devices such as CCDs (Charge Coupled Devices) or C-MOS arrays consisting of imaging surfaces, with pixels arranged in a one or two-dimensional matrix are widely used in digital cameras and scanners.

There is however a growing demand for higher resolution of the images. One way of obtaining a higher resolution is by increasing the number of pixels in the imaging surface of solid state imaging devices. However, if the number of pixels is simply increased in e.g. a CCD to satisfy the need for high resolution, its chip size has to be further increased. On the other hand, in order to increase the number of pixels without changing the present CCD chip size, the integration of pixels must be greatly enhanced. It is technically difficult to prepare such a high-density CCD. Even if development of improved fabrication techniques allows the manufacture of such a CCD in the near future, the circuit configuration for driving such a CCD becomes complicated and power consumption becomes higher, thus entailing new problems, which will result in loss of production efficiency and higher cost.

Other methods for obtaining higher resolution have been used. In scanners the CCD or CMOS array are usually moved in one direction in steps equal to the height of the individual sensors by means of stepper motors, and in special high resolution cameras, the sensor matrix are moved in both an X and an Y directions, to move the individual cells to positions not covered by any cell in the matrix (due to a physical distance between each sensor) or to positions not covered by either a red, green og blue filtered cell. All methods have the limitation that the area of each sensor-cell is limiting the achievable resolution.

US 6,002,810 disclose a method for generating an image having an arbitrary number of pixels starting from a given digitally image having a given number of pixels. This method does not provide a means for improving the resolution and the quality of the image after enlarging will be inferior to the original.

US 4,652,928 relate to a method for improving the actual resolution of an image at the time the image is being established. However, the improvement of the resolution is limited by a factor 2 and is effected solely upon movement in a horizontal direction. Moreover, as already mentioned the achievable resolution is limited by the size of the sensor-cells.

It is therefore an object of the present invention to provide a new and improved method and apparatus capable of attaining higher resolution and realising better image quality cheaper than known up till now.

According to the invention a low resolution first image is converted to a high resolution second image by means of a light sensor for receiving incident light radiated from a scene, whereby said light sensor is constructed as an array or a matrix having a number of cells, each defining a predetermined area.

The method for carrying out said converting is comprising that said first image is cyclically scanned a number of times, that the light sensor simultaneously with the scanning stepwise is moved an identical number of times relative to the light radiating scene in at least one direction thereby defining a number of subareas, that the total distance covered during movement of the light sensor corresponds to the extend of the cell or to to the extend of the cell plus a distance defined by or to the neighbour cell in said at least one direction , and that a representation of the high resolution second image is

established by calculating the representation of the received incident light from the scene at each subarea.

Thereby a method advantageously is obtained in which the calculations are limited to a minimum but were the image resolution is only limited by factors as optics and precision of the positioning mechanism and not by the number and size of each sensor cell, thus giving the possibility of achieving an extremely high resolution, not known by any other method.

The calculating representing the received incident light from the scene at each subarea can advantageously be performed by means of a computer having a software program for receiving the output from the position sensor and on basis of this output calculate control values for bringing the light sensor to move in a wanted way.

If the light sensor for each step is moved a distance corresponding to the extend of the area covered by the cell in the direction of movement, divided with the number of scanning times it is possible, due to the overlapping between the scannings, to have several scannings on the same cell whereby the calculations in the cycle and thus the resolution will become even more accurate.

By an advantageously embodiment according to the invention the light sensor can be stepwise moved by means of at least one driver relative to the light radiating scene, the immediate position of the light sensor can be recorded by means of at least one position sensor generating output representing said sensor position, said output can be send to a computer having a software program for calculating control values on basis of the received output, and signals representing the calculated control values can be send to the at least one position driver for bringing this to drive the light sensor in such a way that

the steps of movement as function of the scannings defines a predetermined curve in a coordinate system.

The predetermined curve can have any appropriate form such as a stairway or be sinusoidal.

Another preferred form is a triangle. By choosing a triangle curve the scannings can be performed with equidistant timely distances while the distance between the positions of the light sensor is identical.

In practise the light sensor can be movable mounted on a frame and cyclically moved along this by means of the drivers simultaneously with scanning the low resolution first image a number of times by means of an activator bringing the light sensor to scan.

The values calculated after all predetermined number of scannings can advantageously be computed by means of the following formula:

$$I_a(z) = V_o + A/a(n) - \Sigma I_a(n) \text{ for } n=1 \text{ to } a=N,\ n \neq z \qquad (1)$$

where

N is the number of subareas that each cell is splitted into,
n is the index for subareas in the sensor cell,
a is the area of the n'th subarea of the sensor cell,
V_a is the output signal from the sensor cells,
I_a is the computed light radiation received by the subarea a,
z is the subarea to be calculated,
A is the total area of the sensor cell.

This formula is based on the assumption that the output from each imaging surface of the individual sensor cells arranged in a two-dimensional matrix is in principle a representation of

the integration of the light intensity on the area of the optical sensor elements:

$V_o = \int I_a(a)da.$

When there is a definite number of subareas a in A, is the formula:

$V_o = \Sigma I_a(n)$ for n=1 to N,

where

N is the number of subareas that each cell is splitted into,
n is the index for subareas in the sensor cell,
V_o is the output signals from the sensor cells,
I_a is the computed light radiation received by the subarea a,

The larger the sensor element is the larger will V_o be. It is however necessary that V_o is independent of the area of the sensor, since a given light intensity always must represent the same V_o. Therefore, V_a is scaled in accordance with the pixel area so:

$V_o = \Sigma I_a(n)$ for n=1 to N, =>
$V_o=(1/A)* \Sigma I_a(n)*a(n)$ for n=1 to N,
where a(n) is the area of the n'th subarea.

This will of course happen automatically in the sensor via exposure time and related technique in the sensor, but the assumption is important for arriving to formula (1).

I_a for a given subarea z is therefore:

$I_a(z) = V_o*A/a(z) - \Sigma I_a(n)$ for n=1 to n=N, n≠z (2)

where

N is the number of subareas that each cell is splitted into,,
n is the index for subareas in the sensor cell,
a is the area of the n'th subarea of the sensor cell,
V_o is the output signals from the sensor cells,
I_a is the computed light radiation received by the subarea a,
z is the subarea to be used for calculation,
A is the area of the sensor cell.

If all subareas have equal area, then A/a(z)=N and (1) can be written:

$I_a(z) = V_o*N - \Sigma I_a(n)$ for n=1 to n=N, $a \neq z$ (3)

The formula in (1) can in general work for any subarea in the entire sensor matrix, meaning that the summation of subareas can cover subareas from other sensor cells:

$I_a(z) = V_o*A/a(z) - \Sigma I_a(n)$ for n=1 to n=N, $n \neq z$ (4)

where

N is the number of subareas that the summation includes,
n is the index for subareas to be summarised,
a is the area of the n'th subarea,
V_o is the output signal from one of the sensor cells, which includes the subarea a(z),
I_a is the computed light radiation received by the subarea a,
z is the subarea to be used for calculation,
A is the area of the entire subareas.

Since the method according to the invention is based on calculated values, or in some instances on estimated values, there will inevitably be generated errors in the calculations.

In a preferred embodiment does the method therefore comprise a digital filter for minimising the errors. The digital filter can e.g. use several values from several different set of input values and the set of previous calculated output values to compute a new output value. This will minimise the influence from errors in calculated values or errors in an output value from a sensor cell. Different types of filters can be used, but the most simple type is based on the formula in (2), where each factor on the right side is weighted with a predetermined value.

In one embodiment of the invention is it assumed that the light sensor is formed as a X,Y-matrix, with respectively X*Y cells.

When the sensor has been moved to a N number of new positions and a N number of sets of output values from the sensor has been stored, a new X_s,Y_t-matrix with X_s*Y_t cells can be calculated. The new matrix having a row of X*S cells and a column of T*Y cells, giving N<=S*T, and the digital filter as a modification of formula (3) can be written in the form:

$$I_s\ (x_s\ ,\ y_t) = F_v * V_o\ (x,y) - \Sigma I_s(x_s - n,\ y_t - m) * F(x_s - n,\ y_t - m) \qquad (4)$$

for $n=1$ to $n=x_s$ and $m=1$ to $m=y_t$; $(n,m) \neq (x_s,y_t)$

where

$I_s\ (x_s,y_t)$ is the light radiation value of the x_s,y_t element in the new X_s, Y_t matrix to be calculated,

$V_o\ (x,y)$ is the sensor output value from the sensor element in the chosen scanning position covering the (x_s,y_t) subarea,

F_v is the predetermined filter coefficient related to the sensor output value from the sensor element in the chosen scanning position covering the (x_s,y_t) subarea,

$I_s(x_s - n,\ y_t - m)$ is previous calculated I_s values, in the new x_s,y_t matrix,

$F(x_a - n, y_a - m)$ is the predetermined filter coefficients related to the previous calculated I_a values for subareas in the new x_a, y_a matrix,
n,m is the number of previous calculated I_a values for subareas in the new x_a, y_a matrix, in the X and Y direction respectively.

This digital filter has the advantage that the filter coefficients for previous calculated values of I_a can be smaller and smaller, thereby ensuring that the influence of errors in previous calculated values are minimized.

The method can by another advantageously embodiment according to the invention also be carried out in such a way that the scanning and the stepwise movement of the light sensor are asynchronous in relation to each other in the sense that each new scanning is taken place in a sensor position not scanned before whereby an almost infinite high resolution is possible by only scanning a sufficient number of times.

The invention also relates to an apparatus for performing the method according to the invention.

This apparatus correspond in general to the known solid state imaging devices known by the skilled person but with the exception that the optical sensor is arranged in a flexible system comprising means for moving said sensor a predetermined or measurable area which are much less than each of the areas of each sensor element.

When the sensor is arranged in a flexible system will the apparatus quickly and accurate be able to make new measurements and output values for each predetermined or measured position.

The apparatus can also comprise a computer provided with a software program for establishing a representation of the high

resolution image by calculating the representation of the received incident light from the scene at each subarea.

The light sensor can preferably be moved by means of an electro-mechanical device or a piezo-element, so that the position of the sensor-matrix can be controlled electrically, and thus the position syncronized to the storing and calculating electronic devices.

A further advantage of the invention, is that each set of output values from the sensor matrix can be transmitted or stored externally together with information about the exact position of the sensor array at the time of the scanning, for calculation in another place or time, for example after transmission through network or storing on digital media. This will give the advantage that no extra computer resources for calculation has to be included in the invented apparatus, but existing resources in the receiving devices can be used.

The invention will be explained in greater detail below, describing only simple idealised exemplary embodiments with reference to the drawing, in which

Fig. 1 shows a sensor cell according to the invention with a matrix 16 subareas a in a first and second position,

Fig. 2a-2c is illustrating the method according to the invention in a matrix with one cell-array,

Fig. 3a-3c is illustrating the method according to the invention in a matrix with one cell-array but were there is a physical distance between the cells in the sensor,

Fig. 4 is illustrating the method according to the invention in a matrix with one cell-array, but where the influence of an

error is minimised by means of a filter according to the invention,

Fig. 5 shows schematically an apparatus according to the invention,

Fig. 6a-6b shows schematically one embodiment of the invention,

Fig. 7a-7b shows schematically another embodiment of the invention,

Fig. 8a-8b shows schematically a third embodiment of the invention,

Fig. 9a-9b shows schematically a fourth embodiment of the invention, and

fig. 10a-10c shows a fifth embodiment of the invention in form of a scanner.

In fig. 1 is shown a sensor cell 1 with 16 equally sized subareas a moved from a first scanning position 2 to a second scanning position 3.

As can be seen there is T = 6 overlapping subareas, which means that the total area N of the overlapping subareas is N=6*a while the entire sensor area A = 16*a.

That means that if the sensor is moved in such a way that the overlapping area only is increasing by the size a of a subarea during each scanning the resolution can as maximum be extended by the size A.

In fig. 2a is illustrated how the original picture 4, consisting of two black squares 5 and two white squares 6, are being processed by the method according to the invention. The

black squares are given the value 0 while the white squares are given the value 256, which are the normal value range used in computer and sensor systems.

The sensor is having a cell-array 7 with 6 cells, and in the next line is seen how the sensor according to the invention is evaluating the image. Each cell is larger than each square in the image. The sensor will therefore not be able to see the correct image resolution. Since each cell only is able to see a number of squares, will each cell give a mean value from the squares. In this case is the first set of squares 5a and 6a and the second set of squares 5b and 6b each given the respective cells mean value of 128 (in the figs. indicated by single-lined right inclined hatching). Therefore, image 8 would be the resulting image in case the image is not further processed.

In fig. 2b is shown how the sensor is making a first scanning 9a, then moving the sensor in the X-direction with a step a, and thereafter making a second scanning 9b.

The incoming output signals from the sensor cells is stored in the electronics attached to the sensor (directly or indirectly) as respectively a first and second set of signals based on each cells incoming light.

The first set of output signal from the sensor is measured as respectively $V_o(1,1)$, $V_o(1,2)$, $V_o(1,3)$, $V_o(1,4)$, $V_o(1,5)$, $V_o(1,6)$, and the second set of output signals are measured as respectively $V_o(2,1)$, $V_o(2,2)$, $V_o(2,3)$, $V_o(2,4)$, $V_o(2,5)$, $V_o(2,6)$. The o stands for output, s for sensor, the numbers denotes the scan number and the cell number respectively.

The new set of calculated I_s light values are denoted respectively $I_s(1,1)$, $I_s(2,1)$, $I_s(1,2)$, $I_s(2,2)$, $I_s(1,3)$, $I_s(2,3)$, $I_s(1,4)$, $I_s(2,4)$, $I_s(1,5)$ $I_s(2,5)$, $I_s(1,6)$. The numbers in the brackets denotes the a value (=1 or 2) and the cell number in

the original sensor matrix that it originates from, respectively.

The new picture, which is shown in fig. 2c is now calculated by means of the formula (3), as the subareas are equally sized.

$I_a(z) = V_o*N - \Sigma I_a(n)$ for $n=1$ to $n=N$, $a \neq z$

where

N is the number of subareas that each cell is splitted into,
n is the index for subareas in the sensor cell,
a is the area of a subarea of the sensor cell,
V_o is the output signals from the sensor cells,
I_a is the computed light radiation received by the subarea a,
z is the subarea to be used for calculation,
A is the area of the sensor cell.

The resolution enhancement factor is in the present case 2, and for each cell is there a overlapping area T of 1.

$I_a(1,1) = V_o(1,1)*2 - \Sigma I_a(a)$, in this specific case is $\Sigma I_a(a)$ not known, as no values has been previously calculated, why an estimate is given, e.g. the mean value of the starting cell, that is $\Sigma I_a(a) = V_o(1,1)$ therefore:

$I_a(1,1) = V_o(1,1)*2 - V_o(1,1) = 256*2-256=256$
$I_a(2,1) = V_o(2,1)*2 - I_a(1,1) = 256*2-256=256$
$I_a(1,2) = V_o(1,2)*2 - I_a(2,1) = 256*2-256=256$
$I_a(2,2) = V_o(2,2)*2 - I_a(1,2) = 128*2-256=0$
$I_a(1,3) = V_o(1,3)*2 - I_a(2,2) = 128*2-0=256$
$I_a(2,3) = V_o(2,3)*2 - I_a(1,3) = 128*2-256=0$
$I_a(1,4) = V_o(1,4)*2 - I_a(2,3) = 128*2-0=256$
$I_a(2,4) = V_o(2,4)*2 - I_a(1,4) = 256*2-256=256$
$I_a(1,5) = V_o(1,5)*2 - I_a(2,4) = 256*2-256=256$
$I_a(2,5) = V_o(2,5)*2 - I_a(1,5) = 256*2-256=256$

$I_a(1,6) = V_o(1,6)*2 - I_a(2,5) = 256*2-256=256$

In fig. 3 is shown how the method according to the invention is operation in case each sensor cell is not abutting on the next sensor cell.

As can be seen in fig. 3a is the image the same image as in fig. 2a, however the sensor cells 7 are seeing the image differently as there is a space b between the cells. Therefore, image 10 would be the resulting image in case the image is not further processed.

In fig. 3b is shown how the space can be covered by three scannings, because the distance between two cells is exactly half the width of a cell. The resulting resolution enhancement will in this case not be equal to N (which is two) as the scannings cover an area which where not covered by the sensor matrix, thereby giving a resolution enhancement of 3.

The sensor is making a first scanning 10a, then moving the sensor in the X-direction with a step a, and thereafter making a second scanning 10b, moving the sensor in the X-direction with step a and making a third scanning 10c.

The incoming input signals is stored in the sensor electronics attached to the sensor directly or indirectly as respectively a first, a second and a third set of signals based on each cells incoming light.

The first set of output signal from the sensor is measured as respectively $V_o(1,1)$, $V_o(1,2)$, $V_o(1,3)$, $V_o(1,4)$, $V_o(1,5)$, $V_o(1,6)$, and the second set of output signals are measured as respectively $V_o(2,1)$, $V_o(2,2)$, $V_o(2,3)$, $V_o(2,4)$, $V_o(2,5)$, $V_o(2,6)$ and the third set of output signals are measured as respectively $V_o(3,1)$, $V_o(3,2)$, $V_o(3,3)$, $V_o(3,4)$, $V_o(3,5)$, $V_o(3,6)$. The o stands for output, the numbers denotes the scan number

and the cell number respectively. A third number would have to be introduced in case of a sensor matrix with more than one row.

The new set of calculated I_a light values are denoted respectively $I_a(1,1)$, $I_a(2,1)$, $I_a(3,1)$, $I_a(1,2)$, $I_a(2,2)$, $I_a(3,2)$, $I_a(1,3)$, $I_a(2,3)$, $I_a(3,3)$, $I_a(1,4)$, $I_a(2,4)$, $I_a(3,4)$, $I_a(1,5)$, $I_a(2,5)$, $I_a(3,5)$, $I_a(1,6)$. The numbers in the brackets denotes the n value (=1, 2 or 3) and the cell number in the original sensor matrix that it originates from, respectively. A third number would have to be introduced in case of a sensor matrix with more than one row.

The new picture, which is shown in fig. 3c is now calculated by means of the formula (3) as the subareas of the sensor cell are equally sized.

$$I_a(z) = V_o * N - \Sigma I_a(n) \text{ for } n=1 \text{ to } n=N,\ a \neq z$$

where,

N is the number of subareas that each cell is splitted into,
n is the index for subareas in the sensor cell,
a is the area of a subarea of the sensor cell,,
V_o is the output signals from the sensor cells,
I_a is the computed light radiation received by the subarea a,
z is the subarea to be used for calculation,
A is the area of the sensor cell.

$I_a(1,1) = V_o(1,1)*2 - V_o(1,1) = 256*2-256=256$ (White)
$I_a(2,1) = V_o(2,1)*2 - I_a(1,1) = 256*2-256=256$ (White)
$I_a(3,1) = V_o(3,1)*2 - I_a(2,1) = 256*2-256=256$ (White)
$I_a(1,2) = V_o(1,2)*2 - I_a(3,1) = 256*2-256=256$ (White)

Same values until $I_a(1,3)$:

$I_e(1,3) = V_o(1,3)*2 - I_e(3,2) = 128*2-256=0$ (Black)
$I_e(2,3) = V_o(2,3)*2 - I_e(1,3) = 128*2-0= 256$ (White)
$I_e(3,3) = V_o(3,3)*2 - I_e(2,3) = 128*2-256=0$ (Black)
$I_e(1,4) = V_o(1,4)*2 - I_e(3,3) = 128*2-0= 256$ (White)
$I_e(2,4) = V_o(2,4)*2 - I_e(1,4) = 256*2-256=256$ (White)
$I_e(3,4) = V_o(3,4)*2 - I_e(2,4) = 256*2-256=256$ (White)
.
.
$I_e(3,5) = V_o(3,5)*2 - I_e(2,5) = 256*2-256=256$ (White)

In both cases is made an estimate of the initial value of $I_e(1,1)$. In case this estimate is wrong or contains an error will the mistake propagate throughout the calculations.

In fig. 4 is shown how one embodiment of the digital filter according to the invention is used for correcting an error.

The original picture 11 in (4) has a grey background (in the figs. indicated by single-lined right inclined hatching) with value 128 and two grey dots (12a,12b) with value 64 (in the figs. indicated by small cross-hatching). With one scan 13 the resulting picture would be 14. According to the invention two scans 15a,15b are used in this example to double the resolution, A=2. The sensor cells measure the grey background correctly with values 128, but the output $V_o(2,2)$ (output from scan 2, sensor cell 2) is due to a distortion or other error, measured as 80 instead of 96, which would be the correct value. This will cause all the calculated new values after $I_e(1,2)$ to be incorrect 16, which can be seen by the following calculation:

$I_e(1,1)= V_o(1,1)*2- V_o(1,1)= 128*2-128 =128$ (Estimated initial value)
$I_e(2,1)= V_o(2,1)*2- I_e(1,1)= 128*2-128 =128$
$I_e(1,2)= V_o(1,2)*2- I_e(2,1)= 128*2-128 =128$
$I_e(2,2)= V_o(2,2)*2- I_e(1,2)= 80*2-128 =32$

$I_a(1,3)= V_o(1,3)*2- I_a(2,2)= 96*2-32 =160$
$I_a(2,3)= V_o(2,3)*2- I_a(1,3)= 96*2-160 =32$
$I_a(1,4)= V_o(1,4)*2- I_a(2,3)= 96*2-32 =160$
$I_a(2,4)= V_o(2,4)*2- I_a(1,4)= 128*2-160 =96$
$I_a(1,5)= V_o(1,5)*2- I_a(2,4)= 96*2-32 =160$
$I_a(2,5)= V_o(2,5)*2- I_a(1,5)= 128*2-160 =96$
$I_a(1,6)= V_o(1,6)*2- I_a(2,5)= 96*2-32 =160$

It is obvious that the error introduced in $V_o(2,2)$ will influence on all the following calculations, and will cause an oscillation even when V_o has stopped changing. This is shown in the resulting picture 16a.

In the calculations of the I_a values in 16b a very simple digital filter according to (4) has been introduced. This digital filter has the advantage that it can use more values from previous measured and/or calculated cells to calculate new I_a values, thereby minimising the influence of noise and other errors:

The filter coefficients are chosen to:

$F_v=2$
$F(-1,0)=0.75$
$F(-2,0)=0.25$ (only one row in the sensor matrix)
All other coefficients in (4) are set to 0.

$$
\begin{aligned}
I_a(1,1) &= V_o(1,1)*2- V_o(1,1)\\
&= 128*2-128\\
&= 128 \text{ (Estimated initial value)}\\
I_a(2,1) &= V_o(2,1)*2-0.75*I_a(1,1)-0.25*I_a(1,1)\\
&= 2*128-0.75*128+0.25*128\\
&= 128
\end{aligned}
$$

($I_a(1,1)$ are used two times, as no present value exist)

$$
\begin{aligned}
I_a(1,2) &= V_o(1,2)*2-0.75*I_a(2,1)-0.25*I_a(1,1)\\
&= 2*128-0.75*128+0.25*128
\end{aligned}
$$

	=	128
$I_a(2,2)$	=	$V_o(2,2)*2-0.75*I_a(1,2)-0.25*I_a(2,1)$
	=	$2*80-0.75*128+0.25*128$
	=	32
$I_a(1,3)$	=	$V_o(1,3)*2-0.75*I_a(2,2)-0.25*I_a(1,2)$
	=	$2*96-0.75*32+0.25*128$
	=	136
$I_a(2,3)$	=	$V_o(2,3)*2-0.75*I_a(1,3)-0.25*I_a(2,2)$
	=	$2*96-0.75*136+0.25*32$
	=	82
$I_a(1,4)$	=	$V_o(1,4)*2-0.75*I_a(2,3)-0.25*I_a(1,3)$
	=	$2*96-0.75*82+0.25*136$
	=	96.5
$I_a(2,4)$	=	$V_o(2,4)*2-0.75*I_a(1,4)-0.25*I_a(2,3)$
	=	$2*128-0.75*96.5+0.25*82$
	=	163
$I_a(1,5)$	=	$V_o(1,5)*2-0.75*I_a(2,4)-0.25*I_a(1,4)$
	=	$2*128-0.75*163+0.25*96.5$
	=	109.5
$I_a(2,5)$	=	$V_o(2,5)*2-0.75*I_a(1,5)-0.25*I_a(2,4)$
	=	$2*128-0.75*109.5+0.25*163$
	=	133
$I_a(1,6)$	=	$V_o(1,6)*2-0.75*I_a(2,5)-0.25*I_a(1,5)$
	=	$2*128-0.75*109.5+0.25*163$
	=	129

In fig. 4 the different values in accordance with the calculation above are indicated by means of different types of hatching.

As can be seen from this example, the error introduced in the measurement of cell $V_o(2,2)$ will not cause oscillations in the following calculations and the influence will disappear. The resulting picture can be seen in 16b.

Fig. 5 illustrates in form of an apparatus 17 by way of example the basic principle for using the invention in a web camera.

The apparatus 17 comprises a light sensor 18 with a number of cells 19 formed as a matrix. The sensor serves for receiving incident light radiated from a scene (not shown). The light sensor is movable mounted on a frame 20. Two drivers 21 are furthermore arranged for cyclically moving the light sensor along the frame in a X and Y direction.

The drivers could e.g. be a piezo-element or an electro-mechanical device.

Each driver is associated with a position sensor 22 for recording the immediate position of the light sensor relative to the frame and for generating output representing said position.

A computer 23 serves for receiving the generated output from the position sensors and for, by means of a software program, calculating control values which via a circuit 24 is send to the two position drivers 21 for bringing these to drive the light sensor 18 in such a way that the steps of movement as function of the scannings defines a predetermined curve in a coordinate system.

The apparatus functions in principle in the way described above with reference to the figures 1 - 16.

More specific, the light sensor 18 is by means of an activator (not shown) cyclically brought to scan the scene (not shown) a number of times.

Simultaneously with the scanning the light sensor is stepwise moved an identical number of times along the frame in the X-Y direction while defining a number of subareas, whereby the

total distance covered during said movements of the light sensor corresponds to the extend of the cell and the distance to the next cell in the X-Y direction, respectively.

During said operation of the apparatus output representing the received incident light from the scene at each sensor cell is send from the light sensor 18 to the computer 23 via another circuit 25, which is shown in bold line.

By storing the received output from the light sensor and adding information about the position of the sensor at the time of scanning by means of another software program, the computer can transmit the pictures and added information to another computer (not shown) by means of the circuit 26 which can be any kind of wired or wireless connection or network. The receiving computer at the other end of the network can then establish a representation of the high resolution picture by calculating the representation of the received incident light from the scene at each subarea.

The calculated representation of the high resolution picture can then be shown on different kind of displaying devices as computer screens and projectors.

The above mentioned curve which is showing the steps of movement as function of the scannings in a coordinate system can within the scope of the invention in itself have any suitable form. In the following advantages and drawbacks of some representative curves are mentioned.

In fig. 6a and 6b is illustrated a simple principle for moving a light sensor 26, which in this case is only moved in the Y-direction. It is, however, obvious that the movement as well could be in the X-direction.

Fig 6b shows a coordinate system where the time of scanning is shown on the axis of abscissas and the position of the light sensor on the axis of ordinate.

The scannings are performed with equidistant time intervals and the distance between each position of the light sensor 26 is identical to these intervals. Thereby the movement of the light sensor as function of the scannings needs to precisely follow a triangle curve as shown in fig. 6b.

Fig. 7a illustrates a sensor matrix 27 moved in the diagonal direction, which is simple to control merely mechanical since the movements only take place in one direction.

The subsequent calculations are, on the other hand, relatively complicated as the subareas are having different sizes, which need to be converted by means of interpolation to equal quadratic pixels elements before being able to show the high resolution picture on e.g. a television screen.

As shown in fig. 7b are the scanning positions asynchronous with scanning times. That means that each new scanning is taken place in a matrix position not scanned before whereby an almost infinite high resolution is possible by only scanning a sufficient number of times.

The distances between the positions of the sensor matrix and the scanning times, respectively, are as in the example shown in fig 6a and 6b equidistant thereby requiring that the curve shown in fig. 7b must be a triangle.

In fig. 8a the sensor matrix 28 is carrying out free oscillations which is the most simple way for mechanically moving the sensor. The oscillations shall, however, still be controlled in such a way that they are kept within the wanted limitations.

Fig. 8b shows a situation where the distance between the scannings is equal in time whereby the distances between the positions of the sensor matrix 28 will be different resulting in complicated subsequent calculations and reduced precision of this calculations.

Fig. 9a and 9b show the same as in fig. 8a and 8b. The only difference is that the distances between the positions of the sensor matrix now are constant whereas the distance in time between the scannings is varying. This mode of using the invention requires in many cases a picture buffer as most receivers, such as computers or servers or the like will require that the pictures arrives with equal distances in time.

Fig. 10a, 10b and 10c illustrate the invention used in a scanner.

In a scanner a sensor matrix having three arrays usually is used. Each array having a red (R), green (G) or blue (B) filter. All colours are scanned in one scan (single pass) while a step motor is moving the three arrays over the object to be scanned.

Some scanners are using only one array. In this case will the filter be changed between each scan, i. e. that the array shall pass the object three times, (multipass).

The resolution in a scanner is depending on the number of elements in the array and of the possible precision of the movement of the arrays. Typically will the resolution in the movement direction of the array be the double of the resolution in the direction of the array itself, conventionally 300x600 dpi or 600x1200 dpi. The distances between each pixel cause this, which typically is in the same order of magnitude as the pixel itself, whereby a higher resolution is possible in the Y-

direction where the step motors can move in steps of precisely one pixel.

By using the invention in a scanner the size of the pixel will not any more be the restricting factor as the array can be moved in the X-direction by means of an arrangement similar to the arrangement shown in fig. 6a.

The movement in the Y-direction can be carried out by means of a step motor, but in even smaller steps independent of the size of the pixels whereby the wanted resolution can be obtained.

This arrangement is shown in fig. 10 showing a scanner 29 having three arrays 30, 31 and 32 of cells R (red), G (green) and B (blue).

One driver 33 are arranged for cyclically moving the arrays in the X-direction.

The driver is associated with a position sensor 34 for recording the immediate position of the light sensor in the X-direction and for generating output representing said position.

A computer 35 serves for receiving the generated output from the position sensors and for, by means of a software program, calculating control values which via a circuit 36 is send to the position driver 33 for bringing this to drive the three arrays cyclically in a wanted mode along the X-axis as illustrated in fig. 10b, while the three arrays is moved along the Y-axes by means of a stepmotor as illustrated in fig. 10c.

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Claims

1. A method for converting a low resolution first image produced by means of a light sensor (18;19) for receiving incident light radiated from a scene to a high resolution second image, whereby said light sensor is constructed as an array (30;31;32) or a matrix (27;28) having a number of cells (1;19), each defining a predetermined area, comprising
   - that said first image is cyclically scanned a number of times,
   - that the light sensor simultaneously with the scanning stepwise is moved an identical number of times relative to the light radiating scene in at least one direction thereby defining a number of subareas,
   - that the total distance covered during movement of the light sensor corresponds to the extend of the cell or to to the extend of the cell plus a distance defined by or to the neighbour cell in said at least one direction, and
   - that a representation of the high-resolution second image is established by calculating the representation of the received incident light from the scene at each subarea.

2. A method according to claim 1, comprising that the light sensor (18;19) for each step is moved a distance corresponding to the extend of the area covered by the cell in the direction of movement or to the extend of the area covered by the cell in the direction of movement plus a distance defined by or to the neighbour cell in the direction of movement divided with the number of scanning times.

3. A method according to claim 1, comprising that the light sensor (18;19) for each step is moved a distance corresponding to the extend of the area covered by the cell plus a distance defined by or to the neighbour cell minus the extend of the area of the smallest subarea to be

calculated in the direction of movement, divided with the number of scanning times.

4. A method according to claim 1, comprising that the light sensor (18;19) is moved asynchronous to the scannings.

5. A method according to each of the claims 1 - 4, comprising that the high resolution second image is computed by calculating the value for each subarea by means of the formula:

$$I_a(z) = V_o*A/a(z) - \Sigma I_a(n) \text{ for } n=1 \text{ to } n=N,\ n\neq z$$

where

N = the number of subareas that each cell is splitted into,
n = the index for subareas in the sensor cell,
a = the area of a subarea of the sensor cell,
V_o = the output signals from the sensor cells,
I_a = the computed light radiation received by the subarea a,
z = the subarea to be used for calculation,
A = the area of the sensor cell.

6. A method according to each of the claims 1 - 5, comprising
- stepwise moving the light sensor by means of at least one driver relative to the light radiating scene,
- recording the immediate position of the light sensor by means of at least one position sensor generating output representing said sensor position,
- sending said output to a computer having a software program for calculating control values on basis of the received output, and
- sending signals representing the calculated control values to the at least one position driver for bringing this to drive the light sensor in such a way that the

steps of movement as function of the scannings defines a predetermined curve.

7. A method according to claim 6, comprising that the predetermined curve describing the steps of movement as function of the scannings in a coordinate system is formed as triangle or a stairway or is sinusoidal.

8. A method according to each of the claims 1 - 7, comprising that the light sensor (18;19) is moved by means of a piezoelectric-element or an electro-mechanical device.

9. A method according to each of the claims 1 – 7, comprising that the scene is moved relative to the light sensor (18;19) by means of a piezo-element or an electro-mechanical device.

10. A method according to each of the claims 1 - 9, comprising that the light sensor (18;19) is moved in a system of x-y coordinates and moved at least in one of the x-y directions of this system or in the direction of a cell of the light sensor.

11. A method according to each of the claims 1 - 10, comprising that the method further comprises a step for minimising the influence of errors in previous calculated or estimated values.

12. A method according to each of the claims 1 - 11, comprising that the influence of errors in previous calculated or estimated values is minimised by means of a digital filter.

13. A method according to claim 12, comprising that the digital filter is using several values from several cycles to compute a filter output value by the following formula

$$I_e(nX_A, mY_A) = (F_{1,1}) * V_0(p_{(1)}X, q_{(1)}Y) - (F_{2,2}) * V_0(p_{(2)}X, q_{(2)}Y) - (F_{3,3}) * \\ \ldots\ldots - (F_{A,A}) * V_0(p_{(A)}X, q_{(A)}Y) - (G_{-1,-0}) * I_e(n_{-1}X_A, m_{-0}Y_A) - (G_{-0,-1}) \\ * I_e(n_0 X_A, m_{-1}Y_A) - (G_{-1,-1}) * I_e(n_{-1}X_A, m_{-1}Y_A) \\ \ldots\ldots - (G_{-n,-m}) * I_e(n_{-n}X_A, m_{-n}Y_A),$$

where,

- $I_e(nX_A, mY_A)$ is the light radiation value of the n,m'th element in the new X_A, Y_A matrix to be calculated,
- $I_e(n_{-1}X_A,\ m_{-0}Y_A]$ is the previous calculated element of the n-1,m'th element of the new X_A, Y_A matrix,
- $(G_{-1,-0})$ is the belonging predetermined filter value,
- $I_e(n_{-0}X_A, m_{-1}Y_A)$ is the previous calculated element of the n,m-1'th element of the new X_A, Y_A matrix,
- $(G_{-0,-1})$ is the belonging predetermined filter value,
- $I_e(n_{-n}X_A, m_{-m}Y_A)$ is the previous calculated element of the n-n,m-m'th element of the new X_A, Y_A matrix,
- $(G_{-n,-m})$ is the belonging predetermined filter value,
- $V_0(p_{(1)}X, q_{(1)}Y)$ is the measured and stored output value of the p, q'th element in the physical sensor matrix overlapping the n, m'th element in the new calculated X_A, Y_A matrix from the first position,
- $(F_{1,1})$ is the belonging predetermined filter value,
- p,q are calculated from n/A and m/A,
- $V_0(p_{(A)}X, q_{(A)}Y)$ is the measured and stored output value of the p,q'th element in the physical sensor matrix overlapping the n, m'th element in the new calculated X_A, Y_A matrix from the A'th position,
- $(F_{A,A})$ is the belonging predetermined filter value, and p,q are calculated from n/A and m/A.

14. An apparatus (17) for converting a low resolution first image to a high resolution second image, comprising

- a light sensor (18) for receiving incident light radiated from a scene to a high resolution second image, whereby said light sensor is constructed as an array (30;31;32) or a matrix (27;28) having a number of cells (1;19), each defining a predetermined area,
- means for bringing the apparatus cyclically to scan the first image a number of times by means of the light sensor,
- means (21;33) for simultaneously with the scanning stepwise to move the light sensor an identical number of times relative to the light radiating scene in at least one direction, whereby the total distance covered during said movement of the light sensor corresponds to the extend of the cell or to the extend of the cell plus a distance defined by or to the neighbour cell in said at least one direction and a number of subareas are defined, and
- means (23;35) for establishing a representation of the high resolution second image by calculating the representation of the received incident light from the scene at each subarea.

15. An apparatus for converting a low resolution first image to a high resolution second image, comprising,
- a light sensor (1;19) for receiving incident light radiated from a scene to a high resolution second image, whereby said light sensor is constructed as an array (30;31;32) or a matrix (27;28) having a number of cells, each defining a predetermined area,
- a frame for movable mounting said light sensor,
- an activator for bringing the apparatus cyclically to scan the low resolution first image a number of times by means of said light sensor,
- at least one driver (21;33) for simultaneously with the scanning stepwise to move the light sensor an identical number of times relative to the light radiating scene in

at least one direction, whereby the total distance covered during said movement of the light sensor corresponds to the extend of the cell or to the extend of the cell plus a distance defined by or to the neighbour cell in said at least one direction and a number of subareas are defined, and

- at least one position sensor for recording the immediate position of the light sensor relative to the frame and sending output representing said position to a computer having a software program for calculating control values on basis of the received output and sending signals representing the calculated control values to the at least one position driver for bringing this to drive the light sensor in such a way that the steps of movement as function of the scannings defines a predetermined curve in a coordinate system.

16. An apparatus according to claim 14 or 15, comprising that a representation of the high resolution second image is established by calculating the representation of the received incident light from the scene at each subarea by means of the formula:

$$I_a(z) = V_o*A/a(z) - \Sigma I_a(n) \text{ for } n=1 \text{ to } n=N,\ n\neq z$$

where

N = the number of subareas that each cell is splitted into,
n = the index for subareas in the light sensor cell,
a = the area of a subarea of the light sensor cell,
V_o = the output signals from the light sensor cells,
I_a = the computed light radiation received by the subarea a,
z = the subarea to be used for calculation,
A = the area of the light sensor cell.

17. An apparatus according to claim 14 or 15, comprising that the apparatus further comprises a digital filter arranged for minimising the influence of at least one error in the value.

18. An apparatus according to claim 14 or 15, comprising that the digital filter are using several values from several cycles to compute a filter output value by the following formula

$$I_a(nX_A, mY_A) = (F_{1,1}) * V_0(p_{(1)}X, q_{(1)}Y) - (F_{2,2}) * V_0(p_{(2)}X, q_{(2)}Y) - (F_{3,3}) * \ldots - (F_{A,A}) * V_0(p_{(A)}X, q_{(A)}Y) - (G_{-1,-0}) * I_a(n_{-1}X_A, m_{-0}Y_A) - (G_{-0,-1}) * I_a(n_0X_A, m_{-1}Y_A) - (G_{-1,-1}) * I_a(n_{-1}X_A, m_{-1}Y_A) \ldots - (G_{-n,-m}) * I_a(n_{-n}X_A, m_{-m}Y_A),$$

where,

- $I_a(nX_A, mY_A)$ is the light radiation value of the n,m'th element in the new X_A, Y_A matrix to be calculated,
- $I_a(n_{-1}X_A, m_{-0}Y_A)$ is the previous calculated element of the n-1,m'th element of the new X_A, Y_A matrix,
- $(G_{-1,-0})$ is the belonging predetermined filter value,
- $I_a(n_{-0}X_A, m_{-1}Y_A)$ is the previous calculated element of the n,m-1'th element of the new X_A, Y_A matrix,
- $(G_{-0,-1})$ is the belonging predetermined filter value,
- $I_a(n_{-n}X_A, m_{-m}Y_A)$ is the previous calculated element of the n-n, m-m'th element of the new X_A, Y_A matrix, $(G_{-n,-m})$ is the belonging predetermined filter value,
- $V_0(p_{(1)}X, q_{(1)}Y)$ is the measured and stored output value of the p,q'th element in the physical sensor matrix overlapping the n,m'th element in the new calculated X_A, Y_A matrix from the first position,
- $(F_{1,1})$ is the belonging predetermined filter value,
- p,q are calculated from n/A and m/A,
- $V_0(p_{(A)}X, q_{(A)}Y)$ is the measured and stored output value of the p,q'th element in the physical sensor matrix

overlapping the n, m'th element in the new calculated X_A, Y_A matrix from the A'th position,

- $(F_{A,A})$ is the belonging predetermined filter value, and p,q are calculated from n/A and m/A.

19. An apparatus according to claim 14 or 15, comprising that the computer (23;35) is provided with a software program for establishing a representation of the high resolution image by calculating the representation of the received incident light from the scene at each subarea.

20. An apparatus according to claim 14 or 15, comprising thatthe predetermined curve is formed as a triangle or a stairway or is sinusoidal.

21. An apparatus according to claim 14 or 15, comprising that the light sensor (1;19) is moved in system of x-y co-ordinates and moved at least in one of the x-y directions.

22. An apparatus according to each of the claim 14 or 15, comprising that the at least one driver (21;33) is an electro-mechanical device or a piezoelectric-element.

23. A use of the method according to claims 1 - 13 and the apparatus according to claims 14 - 21 in a web camera or a still picture camera or camcorder or a monitoring camera or a 360° camera or a digital binocular glasses or a scanner.

Method and apparatus for producing a high resolution image

ABSTRACT

A method and apparatus serves for converting a low resolution first image to a high resolution second image. The apparatus is comprising a light sensor (1;19) for receiving incident light radiated from a scene. The light sensor has a number of cells, each defining a predetermined area, and is arranged for cyclically scanning the low resolution first image a number of times while at least one driver (21;33) is moving the light sensor an identical number of times in at least one direction. For each step the light sensor is moved a distance corresponding to the extend of the area covered by the cell in the direction of movement while the total distance covered corresponds to the extend of the cell in said direction. Thereby a number of subareas are defined. A computer (23;35) serves for establishing a representation of the high resolution second image by calculating the representation of the received incident light from the scene at each subarea by means of a soft ware program. Thereby is obtained a higher resolution and a better image quality than hitherto known.

Fig. 5

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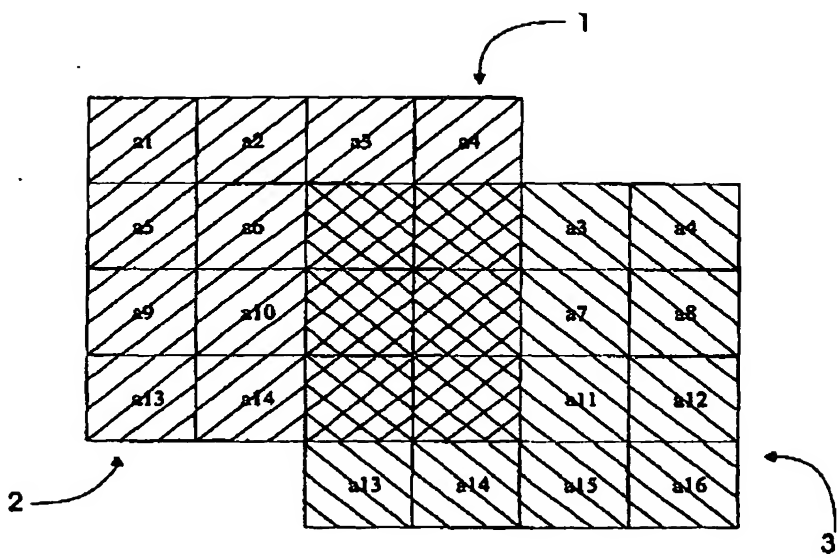

Fig.1

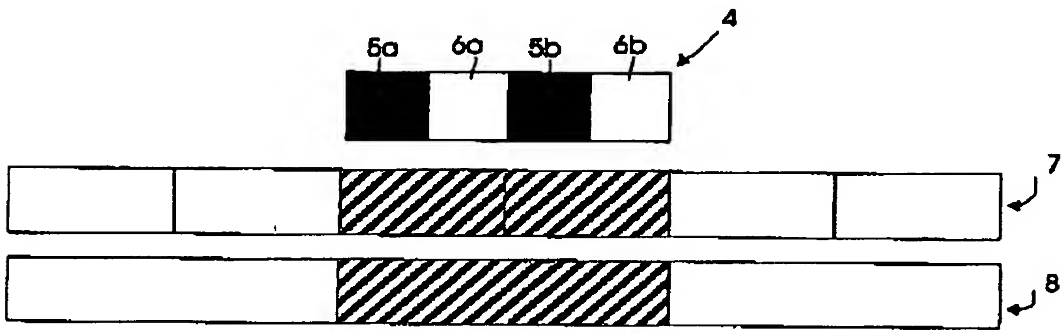

Fig. 2a

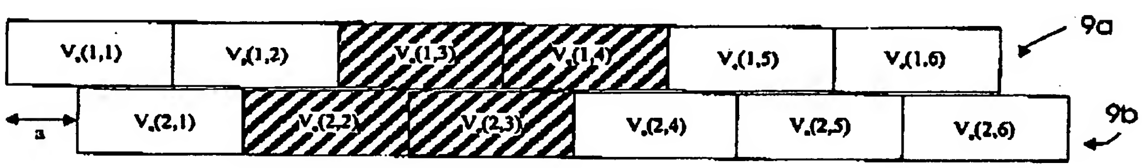

Fig. 2b

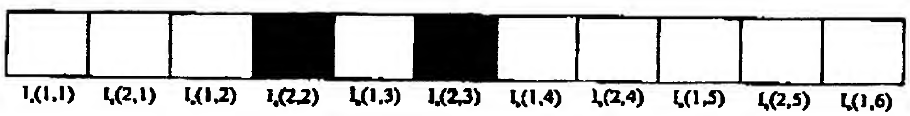

Fig. 2c

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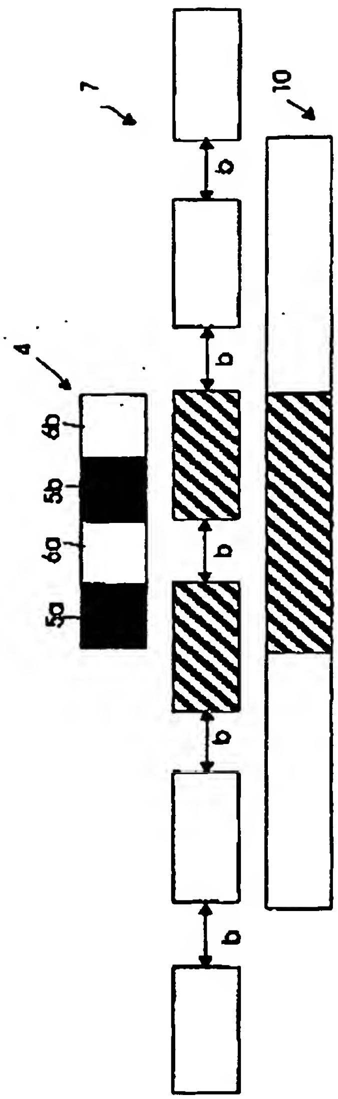

Fig. 3a

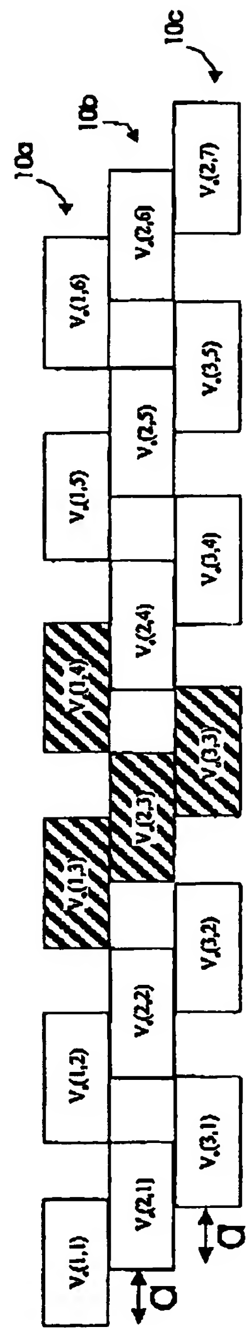

Fig. 3b

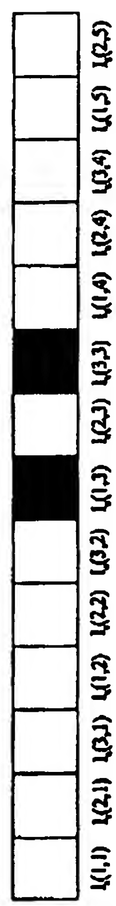

Fig. 3c

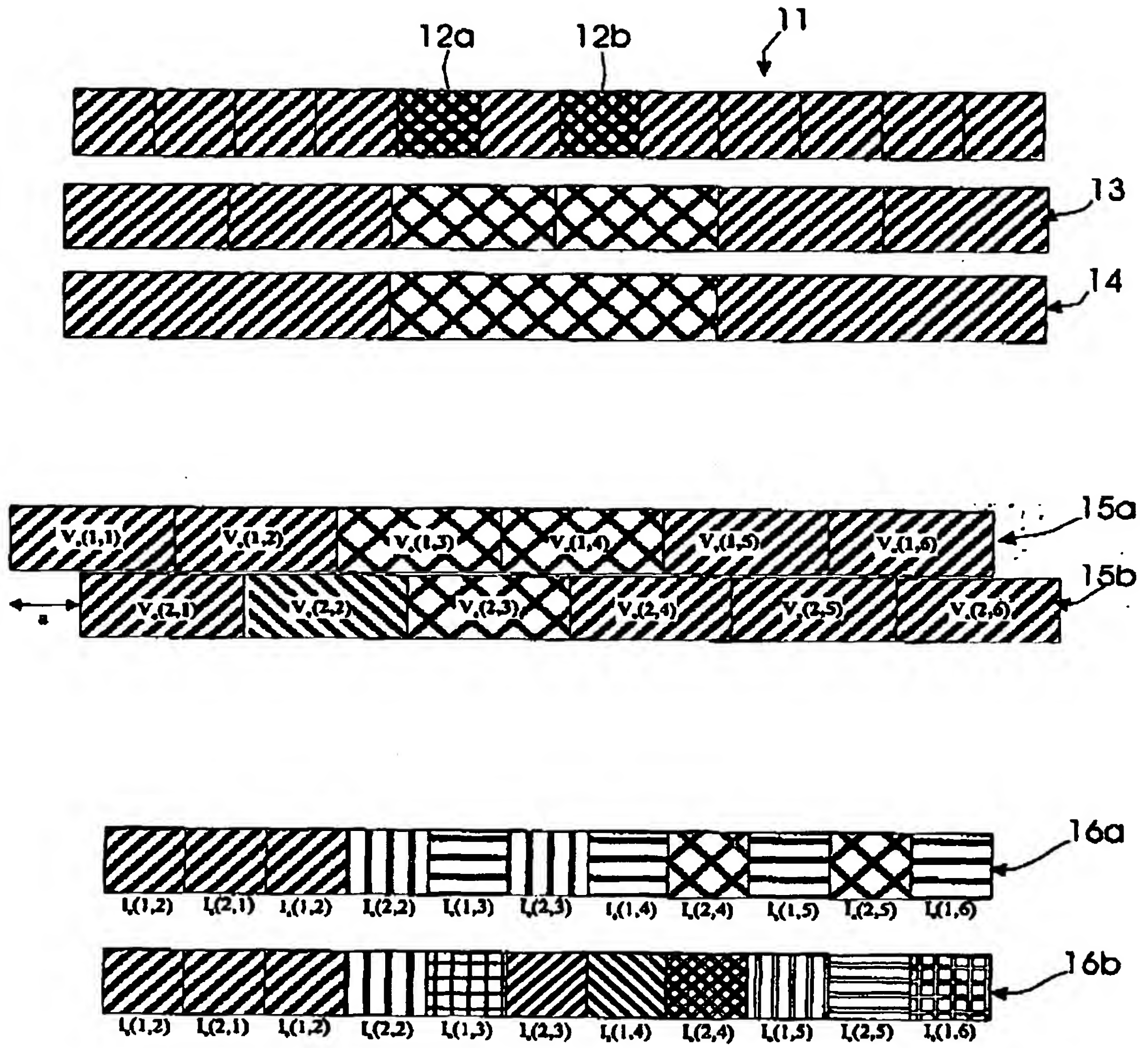

Fig. 4

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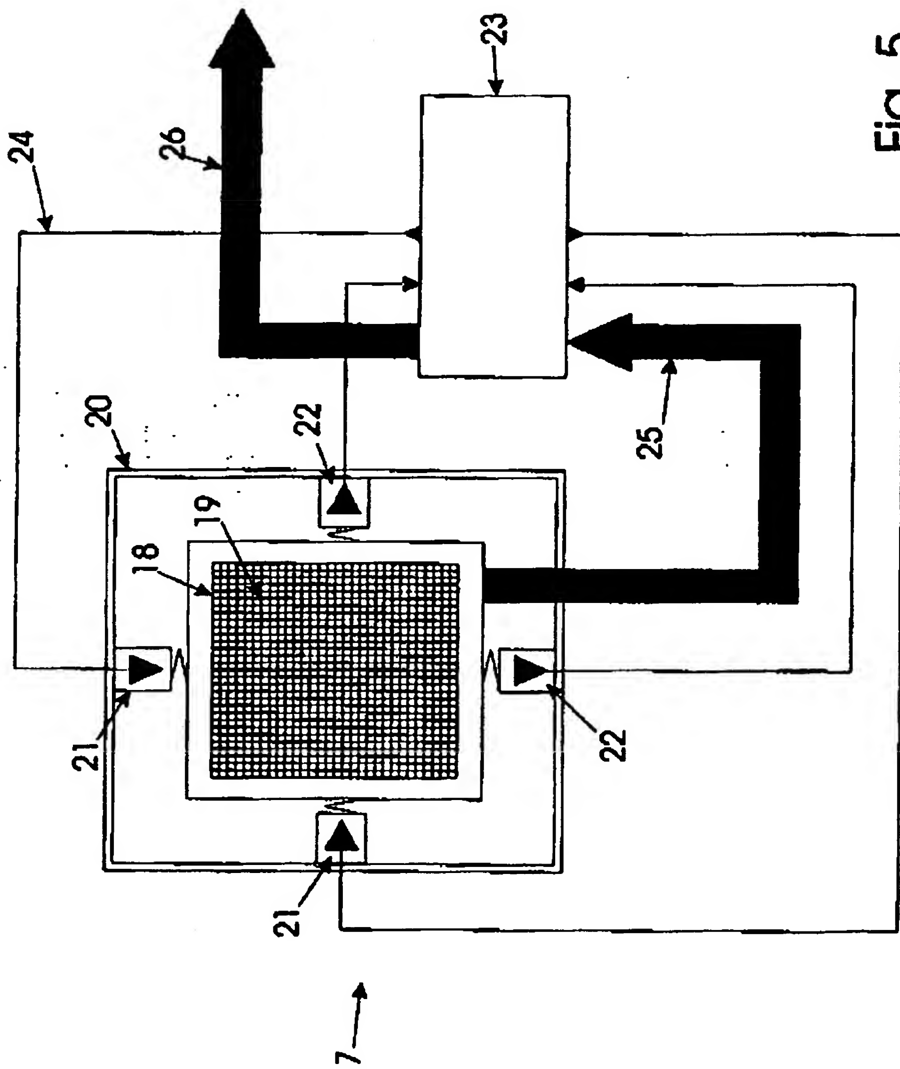

Fig. 5

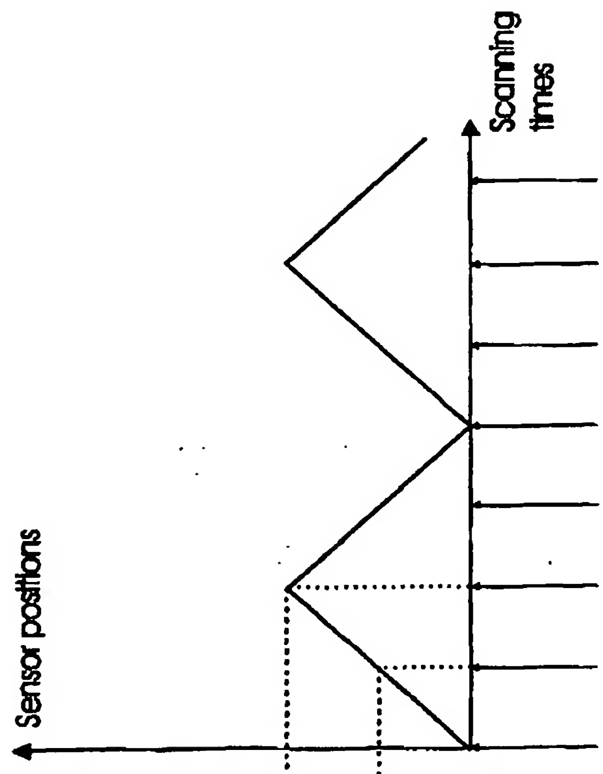

Fig. 6b

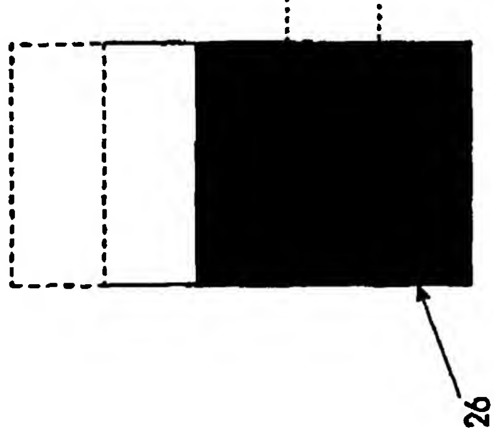

Fig. 6a

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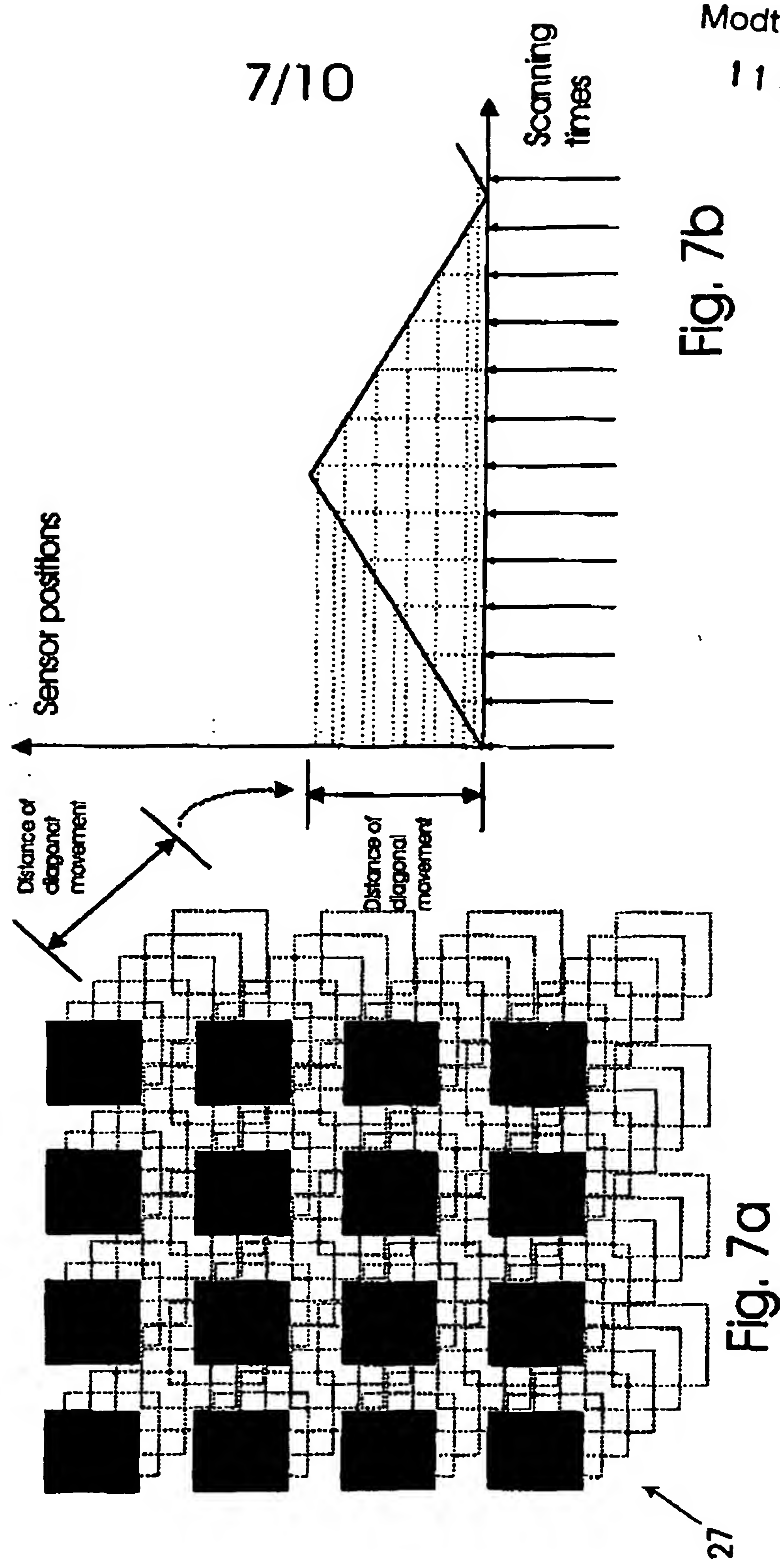

Fig. 7b

Fig. 7a

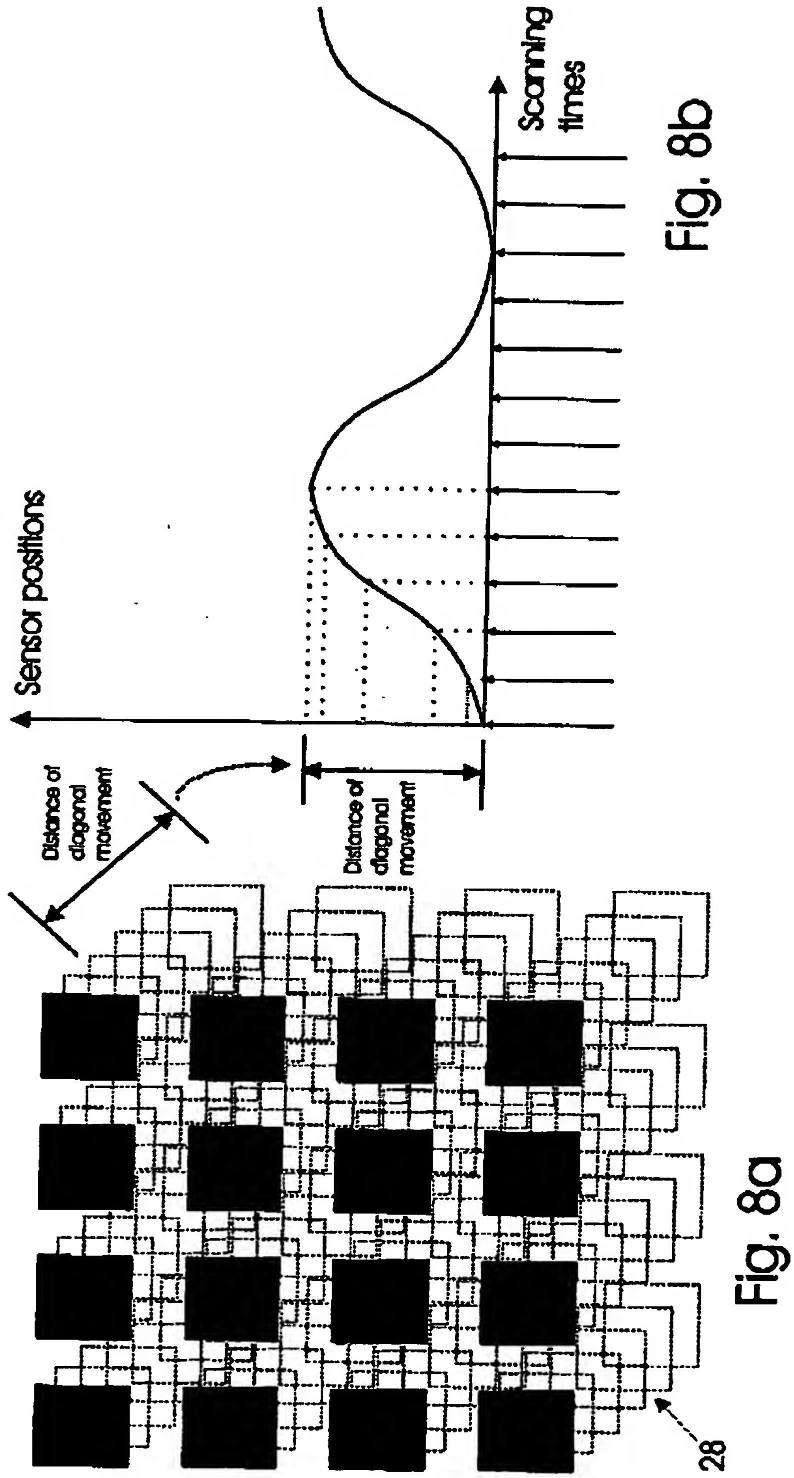
Sensor positions
Scanning times
Distance of diagonal movement
Distance of diagonal movement
28

Fig. 8b

Fig. 8a

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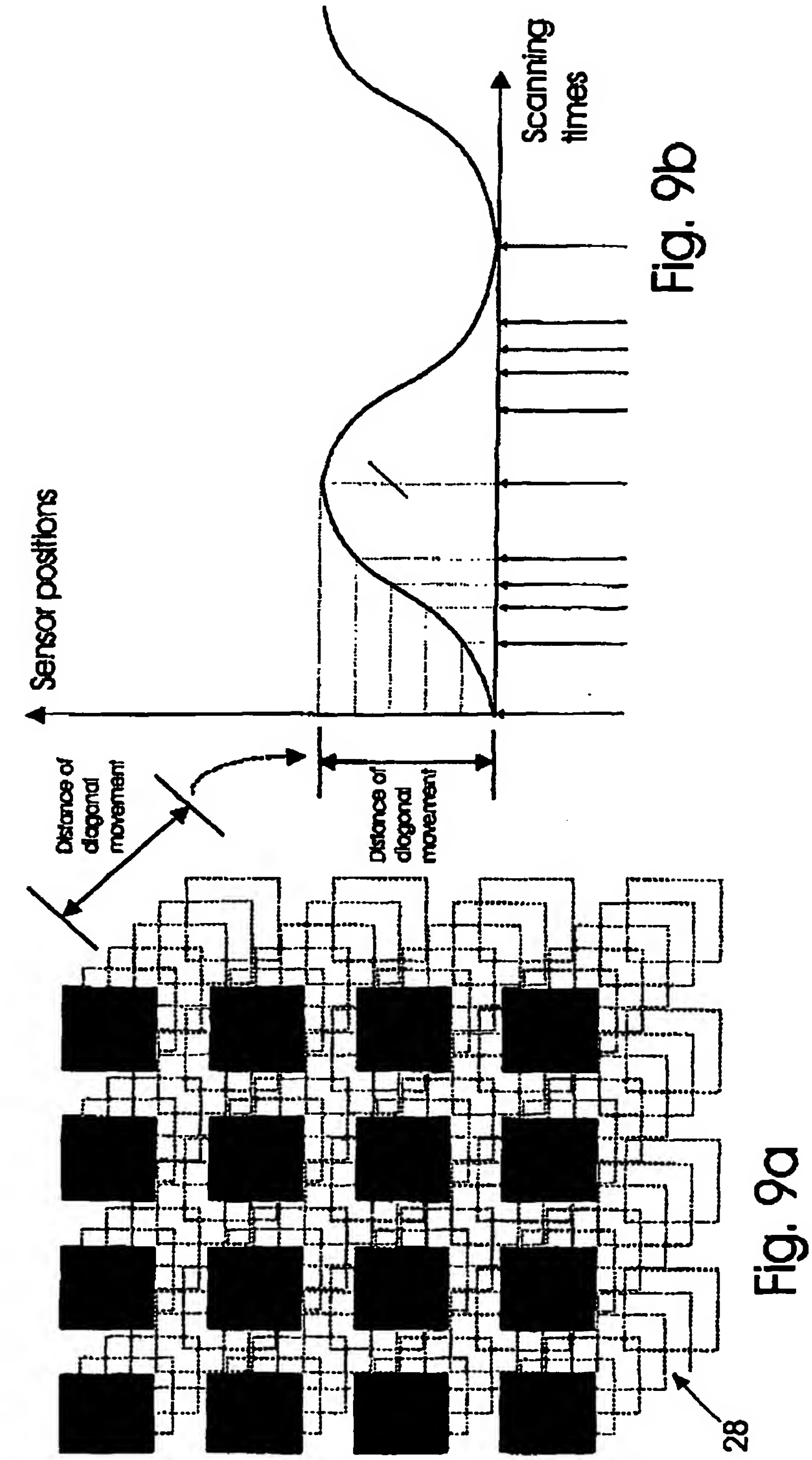

Fig. 9b

Fig. 9a

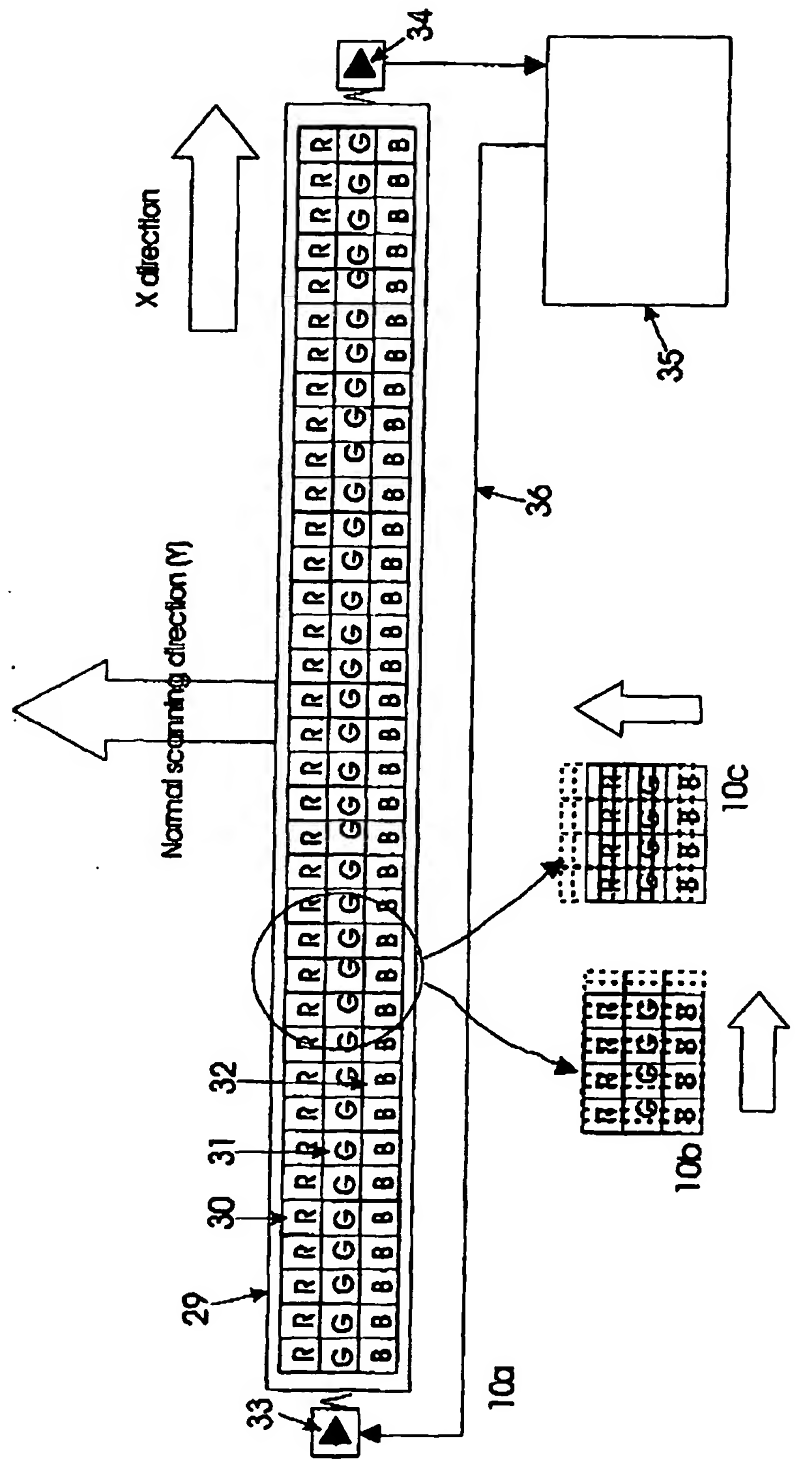
X direction
Normal scanning direction (Y)
34
35
36
29
30
31
32
33
10a
10b
10c

Fig. 10